From the *Journal of Anatomy and Physiology,* Vol. IV.

ON THE DISTAL COMMUNICATION OF THE BLOOD-VESSELS WITH THE LYMPHATICS; AND ON A DIAPLASMATIC SYSTEM OF VESSELS.

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Pl. v. vi.

[The following paper is a *verbatim* copy of one presented to the Royal Society of London in April, 1864. It was illustrated with seventeen coloured drawings, and was accompanied by the microscopic preparations from which the drawings were made. A short abstract appeared in the "Proceedings," June 16 of the same year. I have added in the form of footnotes in brackets some additional remarks where they seemed to be required. T. A. C.]

My attention was first directed to the investigation of the origin of the lymphatics in the early part of 1861 by observing that the liver of one of the lower animals, which I had injected from the portal and hepatic systems, exhibited on its surface the lymphatic network very perfectly distended with the two pigments which had been employed. A similar phænomenon has not, I believe, been unfrequently witnessed by anatomists when injecting the blood-vessels, but the circumstance has been accounted for by supposing that rupture of some arterial or venous twig had taken place, and that the injection had thus gained entrance to the lymphatic system. This, indeed, I regard as the true explanation of the filling of these vessels from the sanguiferous system, or from the ducts of glands when finely divided mineral matters, such as vermilion or chromate of lead, have been used; but in the case to which allusion has just been made, and which will be entered upon in detail hereafter, an explanation of this kind I consider to be totally inadequate. Suffice it here to say, that the conclusion arrived at from the careful and prolonged examination of thin sections taken from this liver and from others subsequently injected, was that direct communication exists between the lymph vessels and those of the blood at their distal as well as at their proximal extremities, and in the former position through tubes of dimensions so small as to preclude the possibility of the blood-corpuscles entering them. From the time my first observations were made on this subject until now (1864) I have been engaged in accumulating further evidence of this communication, and in doing so I have been led to the discovery of another system of vessels, not connected apparently[1] with the lymphatics, but commencing and terminating in the capillaries, and resembling those before-mentioned in being so minute as to admit of the passage only of the liquor sanguinis.

Before entering upon my own special investigations, it will be advisable to narrate briefly what has been said, and more important still, what has been done by modern labourers in this field of inquiry, or, at any rate, in those which border closely upon it.

It will scarcely be necessary for me to canvass the opinions of the older authors respecting the origin of the lymphatics, knowing as we do that to cope with questions so delicate as this the most modern appliances are required. I therefore entirely refrain from quoting opinions which must, from the nature of the case, have been based upon observations of an unavoidably imperfect character.

So long ago as 1845 Mr Goodsir directed[2] special attention to certain corpuscles which had been previously noticed by anatomists in some of the textures, but which had up to that time been looked upon for the most part as the remains of embryonic life. Mr Goodsir, however, discovered that such corpuscles are common to all textures and organs and to all stages of existence, and hence concluded that their functional importance in the animal economy must be very great. To use his own words he believed them "to draw from the capillary vessels, or from other sources the materials of nutrition, and to distribute them by development to each texture and organ after its kind." In accordance with this view he named these corpuscles "centres of nutrition," or, following the nomenclature of the embryologists, "germinal spots." He further defined a nutritive centre as "merely a cell," the nucleus of which is the permanent source of successive broods of young cells" (*Anat. and Path. Obs.* p. 2, 1845); and he held the nuclei of muscle, the cells of areolar tissue, and the corpuscles of bone to be examples of these centres. The branching processes or canaliculi of the bone cells he regarded as "channels for the passage of nutriment from the capillaries to the calcigerous cells and germinal centres" (*Ibid.* p. 66); and the tubules of dentine have also long been supposed by anatomists to perform functions similar to the canaliculi of bones, of which indeed they would seem to be but modifications, and with which they are often in direct communication. A canalicular or juice-carrying system of vessels was thus early recognised as appertaining to the hard tissue of bone and tooth. In 1851, however, Virchow (*Würzburg Verhandl.* Bd. 2, s. 159), and about the same time Donders (*Zeit. für Wissen. Zool.* Bd. 3, p. 348) and Von Wittich (*Würzburg Verhandl.* Bd. 2, 1851), observed that the corpuscles of white fibrous, or connective tissue, were generally of stellate form, and possessed delicate prolongations which anastomosed freely with those of neighbouring cells. From this observation, and probably bearing in mind the relation which white fibrous tissue bears to bone, Virchow was led to believe that the network thus formed is tubular throughout, and employed in the distribution of nutritious juices to the surrounding textures; Kölliker too (*Elements d'Histologie humaine,* Paris, 1856, p. 73), falling in with Virchow's ideas, has denominated these cells and their prolongations "plasmatic cells" and "tubes" respectively; but neither of these authors has, as it appears to me, brought forward any direct evidence of the correctness of their surmises. Virchow believes this "juice-canal-system" to be entirely unconnected with the blood-vessels (Virchow's *Cellular Path.* p. 94, by Chance), and in no way similar to the supposed "vasæ serosæ" of the older anatomists; he believes it, if I understand him rightly, to be essentially a closed system of vessels. Leydig, on the other hand, supposes that the prolongations of connective-tissue corpuscles are continuous with the lymphatic vessels, and he has given in his *Lehrbuch der Histologie,* p. 403, 1857, a diagrammatic representation of his views. Recently he has gone further[1] even than this, and from examinations he has made concerning the relationship of the blood-vessels to the connective-tissue in various organs, he thinks it "possible" that an open communication exists between the blood-vascular and lymphatic systems. One of the latest writers on this subject, Von Recklinghausen[1], affirms that he has been able to trace the continuity of the juice-canals with the finest lymphatic vessels in those organs which he has subjected to examination. Opposed to the views of Leydig and Von Recklinghausen are those entertained by the majority of anatomists who, as is well known, hold that both the lymphatic and blood-vascular systems are closed and unconnected at their distal terminations; and recently Schweigger-Seidel and Teichmann have, as they imagine, proved by injection that the walls of the lymphatics are impermeable even to the finest pulverised substances, and that no direct passage exists between the uninjured blood-vessels and the uninjured lymphatics (*Med. Chir. Rev.*, July 1863, p. 232). Such then is a brief statement of the contradictory views held by the more modern inquirers who have given their attention to the origin and connexion of the smallest lymph-vessels. Were I to attempt a critical analysis of the various papers written on this subject, it would render this communication unnecessarily long. I shall therefore now proceed to describe my own methods of research and the results which I have obtained, leaving these results either to contradict or confirm the statements, which have hitherto been made, regarding the anatomical relations of the minutest lymphatic vessels.

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[1] [i. e. as far as could be actually seen. 1869.]

[2] [*Anatomical and Pathological Observations*, 1845. *Anatomical Memoirs*, Vol. II. Edinburgh, 1868.]

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[1] So stated by Von Recklinghausen in *Die Lymphgefässe.*

As the results which I am about to record possess something of novelty and will therefore raise doubts touching their accuracy in many minds, it will be well to give some account of the method followed and the materials employed in these researches, so as to avoid all unnecessary discussion and scepticism founded on erroneous suppositions.

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[1] *Die Lymphgefässe und ihre Beziehung zum Bindegewebe*, 1862.

[Recklinghausen however attaches a different meaning to the term 'juice-canals' than do Virchow, Kölliker and Leydig. With them the connective tissue corpuscles are the juice-canals. But with Recklinghausen the juice-canals form a system of inter-communicating spaces, having a free communication with the lymph vessels, which surround and enclose the corpuscles of the connective tissue. Moreover he does not think that these canals are tubes with special walls, but excavations as it were in the connective tissue. Neither does he agree with Brücke and Ludwig in conceiving them to be mere interstitial spaces, for he believes that the fibrous bundles and lamellæ of the connective tissue are cemented together by a homogeneous, firm material in which the juice-canals are situated. In an article on the lymphatic system, which has just appeared in the 2nd part of Stricker's *Handbuch* (Leipzig, 1869), Recklinghausen states, in opposition to the opinion he formerly entertained, that he now thinks it possible that the juice-canals have an open communication both with the blood and lymph vessels; and he refers to some recent experiments by Dr Rud. Böhm, made by the application of nitrate of silver to the synovial membrane, which seem to show a similar passage of the juice-canals into the blood-capillaries. Note, October, 1869.]

Whatever success I may have attained to in the present inquiry, I consider to be almost solely attributable to the use of transparent injection of extraordinary penetrating power, consisting of carmine precipitated in gelatine from its ammoniacal solution by acetic acid. The formula for this injection I published in Beale's *Archives of Medicine,* No. xii. 1862. Besides its valuable penetrating qualities it possesses intense brilliancy of colour, and does not stain the textures with which it may come in contact. I insist especially upon this latter property, because many of the carmine vascular preparations with which the public are now familiar, exhibit decided evidence of the pigment having permeated the coats of the vessels and tinted the surrounding tissues,—a knowledge of which circumstance might act prejudicially against the acceptance of my conclusions. I do not deny, however, that under certain very exceptional conditions of the blood, as, for example, great alkalinity, staining of the texture may to a slight extent occur, but such staining will by the experienced eye be easily recognised. The distinguishing characteristic of tinting by the carminate of ammonia is that the nuclei of the tissues become much more intensely coloured than the cells or fibres; but carminic acid, as it exists in my injection, produces no such effect upon the nuclei.

Occasionally, during my investigations, I have resorted to another transparent injection. This was made by precipitating Turnbull's blue (the ferrid-cyanide of iron) in gelatine, and then slightly acidifying the mixture with acetic acid. Like the carmine injection this also is very penetrating, but it is not so much to be depended on in consequence of the rapidity with which the blood and tissues exert a decolorising influence on it. The colour, it is true, may be restored by the application of an acid, but I have found that in its colourless condition it is both soluble and diffusible. If, therefore, the tissues outside the blood-vessels have been impregnated with the iron salt, a blue tint will be developed in them also by the action of the acid, and the preparation thus rendered useless for purposes of observation. With the view of avoiding the alkalinity generated by post mortem changes, I have, in every available instance, injected the animals immediately after death, i.e. as soon as respiration had entirely ceased. In the case of the human subject this of course could not be accomplished. I now enter upon the subject proper of this paper.

If a young frog be killed and the palate, after having been dissected from the base of the skull be examined with a quarter inch objective, the first thing that strikes the observer is the motion of the cilia; on focussing a little deeper the large epithelia to which the cilia belong are brought into view, and still lower are seen the capillaries with the contained blood-corpuscles. If the membrane be now macerated in water for a short time and brushed gently with a camel's hair pencil, a thick layer of viscid mucus will be removed, and with it, in some parts, the ciliated epithelial cells. On re-examination it will be found that the membrane presents a honey-combed appearance in those parts from which the superficial cells have been detached, but by focussing deeper there is brought into view a number of finely granular nucleated cells, possessing for the most part three divergent processes which anastomose with the corresponding processes of neighbouring cells, and in this way form a network. In the centre of each mass may be seen the nucleus of a cell, which lies on a somewhat lower level than the nuclei of the granular network. From this then it follows that in the mucous membrane of the frog's mouth three distinct layers of cells are recognisable, first, the ciliated epithelium, next, the granular cell-network, and last, globular nucleated cells, Pl v. fig. 1. Upon this lowest layer rests directly the ciliated epithelium, so that the network occupies the space intervening between the superficial and deep layers, and also the space existing between the cells of each separate layer. This description will be better understood by referring to Pl. v. fig. 2, which represents a profile view of a fold of the urinary bladder of the frog, where a similar arrangement of parts presents itself.

From this drawing it will be seen that the processes of the cell-network extend not only in the horizontal, but also in the vertical direction, passing upwards between the surface layer of cells as well as downwards between the cells of the basement layer. How the vertical processes terminate either above or below is not shewn in the drawing, nor can this be made out satisfactorily unless other modes of preparation are resorted to.

So far as I am aware the network just mentioned has hitherto been entirely overlooked by histologists with the exception perhaps of Burckhardt[1], who describes three layers of cells in the mucous membrane of the urinary tract in man, the middle layer consisting, he says, of caudate and variously branching cells the processes of which lie perpendicular to the surface. His second layer I strongly suspect corresponds to the second layer which I have noticed in the buccal and vesical mucous membrane of the frog, and which I shall now proceed to shew is both tubular and pervious throughout; and I hope furthermore to demonstrate that this network is in actual communication with the blood-vascular system, and from that system derives its supply of fluid.

How I came to a knowledge of this very singular and important fact I will now relate. In the early part of March 1863, a full-grown female frog, which I had kept in a glass jar from the previous October, from some unascertained cause died. Knowing that this animal had had no food while in my possession, and inferring from this circumstance that the tissues would be in a very relaxed condition, I thought it would afford a good opportunity for observing if the lymphatics could be filled with injection conveyed through the blood-vessels. I accordingly introduced an injecting pipe into the aorta of the previously warmed animal, and fully distended the vessels with the preparation of carmine and gelatine. On examining the membranes of the palate with a low power, after the removal of the mucus, I perceived an exceedingly delicate but perfectly regular carmine-coloured network lying in the interspaces of the capillaries. My first impression was that extravasation had taken place and that the reticulated appearance was due to the injection having insinuated itself between the superficial epithelial cells of the part. On subjecting the preparation, however, to more minute scrutiny under the quarter of an inch object-glass, it became perfectly evident that this explanation was untenable, the network being as well defined and distinct under the high power as the capillary network was under the low one. Thus magnified, the nuclei of the lowest layer of cells were clearly defined, the centre of each mesh being occupied usually by a single nucleus, and the whole structure forcibly reminding one of Henle's[1] drawing of the wall of an air vesicle of the human lung which had been injected and afterwards tinted with carmine. In the less perfectly injected portions of the palate the junction of the cell-network with the capillaries could be readily observed. The communicating branches were here seen to arise chiefly, though perhaps not entirely, from certain bulgings noticeable in the capillaries of this structure. Although my preparation exhibited most satisfactorily the source from which this minute network derived its supply of fluid, I was unable to determine with certainty into what vessels the fluid was again emptied. Considering the small size of the channels of the cell-network as compared with the blood-corpuscles lying in the capillaries close by, and the impossibility of such corpuscles entering the network, it became evident that the liquor sanguinis alone could be admitted; considering further that liquor sanguinis is but lymph in a state of concentration, I was led to believe that I had obtained an unequivocal demonstration of the distal union of the blood-vascular with the lymphatic system. I must confess, however, that being unable to recognise any lymphatic trunks arising from the network, I am not prepared to assert that in this instance I have given sufficient proof of the intercommunication of the two systems. Nevertheless, in support of this idea, I may be allowed to mention that the lymphatic hearts situated on the lower part of the dorsum of this animal were filled with the injecting fluid diluted apparently with lymph, but by what route the injection gained entrance to these receptacles I am not in a position to state.

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[1] Virchow's *Archiv*, Band 17, Hefte 1 and 2, p. 94.

That the network communicates freely with the capillaries at numerous points even in a single mesh, is perfectly certain; it is therefore by no means improbable that it may both commence and terminate in the capillary vessels, thus constituting what might be styled an intercapillary plexus. Certainly if all theoretical considerations were laid aside and an opinion founded solely upon what could be seen in my preparations, the network would have to be regarded as absolutely intercapillary; but notwithstanding the extensive and seeming exclusive connexion of this plexus with the blood-vessels, I am not as yet inclined to give up simply upon negative evidence the possibility of its being united also with the lymphatic system, at certain points which have at present eluded my observation. Be this as it may, the very existence of a network communicating directly with the blood-vessels, and yet lying above the site of the so-called basement membrane, is of itself a fact, I think, of the highest interest for the physiologist. The relation which the channels of this network bear in point of size to the capillaries and blood-corpuscles may be ascertained from the following table. The measurements were taken from an injected palate which had been soaked in glycerine and acetic acid and subsequently mounted in preservative gelatine.

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[1] *Handbuch der Anatomie des Menschen*, Bd. 2, p. 283.

Capillaries........................from $\frac{1}{2000}$ to $\frac{1}{1000}$ of inch.
Blood-corpuscles, trans. diam. from $\frac{1}{1400}$ to $\frac{1}{2000}$ of inch.
Network (diaplasmatic) ......from $\frac{1}{4300}$ to $\frac{1}{8600}$ of inch.

A comparison of the measurements will suffice to shew the correctness of what I previously stated respecting the impossibility of the blood-corpuscles entering the cell-network.

I am inclined to apply the term diaplasmatic at least provisionally to this nucleated network, as well as to the minute vessels to be hereafter mentioned, which connect the capillaries with the lymphatic radicles. In both cases the networks are pervious and will only admit the liquor sanguinis or blood-plasma. This term therefore appears to be sufficiently expressive of their character.

Since my first successful injection of the frog's palate, I have made numerous similar experiments in a like direction and very frequently with the same positive results. This network, it must be understood, is by no means confined to the mucous membrane of the mouth. I have traced it by means of injection down the whole length of the œsophagus and even into the stomach; and I have also seen evidence of it in the large intestine and bladder of the frog. The network may likewise be injected in parts of the toad corresponding with those which I have just mentioned. The most perfect indeed of all my preparations of the cell-network was obtained from the mucous membrane of the eyelid of a toad which was injected immediately after death. I need not, however, stop to describe this plexus inasmuch as it presents a character precisely similar to that which is observable in the roof of the frog's mouth. I may say, indeed, that the network is of uniform appearance in all those parts to which I have hitherto alluded. In the lungs of the toad the network appears to be somewhat modified and developed to a very limited extent; but I have succeeded in proving by injection that vessels exist in these organs which are much smaller than the capillaries, and which are incapable of admitting the corpuscles of the blood. Such vessels may be seen in my preparations as represented in Pl. v. fig. 3, emerging sometimes from the sides, sometimes from the inner surface of the capillaries, and either extending from blood-vessel to blood-vessel completely across the mesh, or as is more commonly the case, traversing it for a short distance only and then terminating in a finely pointed or rounded extremity. The course taken by these vessels is seemingly always between the faint nuclei and cells which stud the mucous membrane of the air vesicles. As I think it probable that many persons on examining the drawing or the preparation from which it was taken, may be disposed to believe that the minute emergent processes which have been filled with injection, are nothing more than developing blood-capillaries, it is but proper to mention that the toad which furnished the preparation was quite full-grown; and was indeed one of the largest I have ever seen.

After having injected a very large number of frogs and toads and in every instance carefully scrutinized their integuments for evidence of the cell-network, I must admit that I have not yet obtained a demonstration which I should consider capable of convincing a sceptical person of its existence in this structure. Nevertheless, certain appearances (discarding analogy), have led me to suppose that such a plexus does exist in the skins of these batrachians[1].

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[1] Quite recently (April, 1864), I had convinced myself by several different modes of preparation that a nucleated network was present in the epidermic

During the early part of the summer of 1863 I made several attempts to fill the blood-vessels of fishes with the carmine injection, and I at length so far succeeded with a small perch as to display the capillaries distributed over its scales as well as those supplying the pectoral fins. In several parts of the membrane uniting the fin-bones there could be seen, when the $\frac{1}{4}$ inch objective was used, a tolerably regular and beautiful network bearing a close resemblance to that found in the frog's mouth, but differing from it in being much more minute (see Pl. VI. fig. 4). As in the frog's plexus, so likewise in this, a nucleus could be recognised occupying the centre of each mesh.

Although my efforts towards demonstrating the diaplasmatic network in the proper epidermal portions of the skin of man and the other mammalia have not been so satisfactory as could be desired, I have so far succeeded in this direction as to have injected it in the base of the hair bulbs of some of the lower animals and more frequently in the parietes of the hair follicle. As yet I have only detected the network in the roots and follicles of the large whisker hairs of the mole, mouse and kitten. In these parts each mesh is occupied by a single globular nucleated cell[1].

Up to this point I have drawn attention to an extremely minute vascular system which is in direct communication with the blood-vessels but which on account of its minuteness can only be supplied with as it were filtered blood, *i.e.* blood minus the corpuscles; and in all the illustrative examples I have yet brought forward, the plexus has been confined to the mucous

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layer of the skin of the palm of the hand. The larger nucleated swellings occupying the space between two or more contiguous cells, while the branches slant very obliquely upwards and downwards between the superimposed cells.

The plexus is more fully developed in the lower epidermal layers than in any other parts.

As I have not been able to prove the network to be in communication with blood-vessels, I have not thought it proper to insert these remarks in the body of the paper, or necessary to describe the particular method employed in exhibiting the plexus.

[1] Since writing the above I have been fortunate enough to discover in an injected preparation of the human tongue a network homologous with that of the frog's mouth; but confined, so far as I have yet been able to prove, to the inner surface of the tonsil-like mucous follicles situated at the posterior part of the dorsum of this organ. In aspect this plexus is very similar to that found in the buccal cavity of the frog, but it is of course of much greater minuteness. From it I have seen arise certain irregular vessels which must, I think, be looked upon as the lymphatics of the part.

membrane and skin, and to that particular portion which lies to the outside of the so-called basement membrane. Now, however, I shall proceed to shew that similarly minute vessels are to be met with in the deeper parts of the organism, as in the nervous, muscular and osseous tissues, and in certain glands; and I shall furthermore attempt to shew that as on the one hand the networks are connected with the blood-vessels, so on the other they communicate with the lymphatics—I hope at least to be able to prove this distinctly in several well marked instances.

The human liver, as well as the liver of the pig, is largely supplied with lymphatic vessels, and both are well adapted for exhibiting the general character and arrangement of the minuter branches of this system of vessels. As these organs have, moreover, in my hands given the most decisive proofs of the intercommunication of the blood- with the lymph-vessels I would specially recommend them to the notice of those who may wish to test the accuracy of my statements. I have now injected the portal and hepatic vessels of three human livers, and of the livers of three pigs, and in each instance the superficial lymphatics were distended with injection of a colour resulting from the admixture of the two pigments employed. In the organ I first experimented upon (a pig's liver) the portal system was filled with a blue fluid, composed of recently precipitated Turnbull's blue, suspended in a mixture containing ferrid-cyanide of potassium, acetic acid, alcohol, sugar and water, and the hepatic vessels with carmine and gelatine, but in all the subsequent experiments the blue colouring-matter was suspended in gelatine. The three pigs' livers so treated displayed the lymphatics on their surface in the form of a comparatively speaking large network, the branches of which could without difficulty be distinguished from the blood-vessels by their generally knotted appearance, as well as by their sudden increase and diminution in size. In the pig each superficial lobule is almost, and in many cases, entirely, encircled by a lymphatic vessel or vessels; but in addition to this many branches and loops proceed from the circumference towards the centre of the lobules, the branches diminishing very rapidly in size and terminating to all appearance in very fine pointed extremities (see Pl. V. fig. 4). How these minute vessels terminate or rather commence in this position it is hardly possible to decide by actual observation, because the dense underlying network of capillaries being filled with injection of the same colour obscure the view; but inferentially we are warranted in concluding that they derive their supply of fluid from the blood-vessels, because in almost every part of the organ which I have examined the commencing lymphatic twigs are occupied with injection of the same tint as the capillaries in close relation to them. Thus, if the capillaries are observed to be violet or red-purple, the lymphatics close at hand will be of a similar colour up to the next valvular swelling, and perhaps beyond it, which circumstance I think clearly proves the continuity of the two sets of vessels. Of course portions of the organs may be singled out where the reverse of this obtains, but such an occurrence is easily explained by the very free anastomoses of the lymphatics, and it in nowise vitiates the correctness of the general conclusion. I have on several occasions seen what I considered to be the actual anastomotic processes of the lymphatics joining the capillaries towards the centre of the lobule in thin sections cut from the surface of the liver; but I would not wish to speak too positively on this matter for reasons which I have before stated. There is no difficulty however in tracing the lymphatics in this part until they become so much reduced in size as to be far less in diameter than the ordinary capillaries of the viscus or even of those supplying the capsule of Glisson (see Pl. VI. fig. 2).

In preparations taken from human livers which I had injected from the portal and hepatic systems with two colours the attenuated radicles of the lymphatics are seen to lose themselves amidst, or (I think I may say after careful and prolonged observation) terminate in the proper capillaries of the organ; and as in the case of the pig the minute lymphatics are almost invariably of the same tint as the capillaries in contact with them, thus shewing from whence they derive their supply of fluids. I have one preparation in my possession which illustrates this in a very striking manner. A lymphatic is observed pursuing a direct course upon the surface of the organ, and is divided into three pretty equal compartments by two valves:

each compartment is filled with injection of a different colour, the first being blue, the second purple, and the third red; whilst the capillaries in the neighbourhood of each compartment are occupied with injection of an exactly corresponding tint[1].

In sections obtained from the surface of the human liver in the immediate vicinity of the hepatic artery (*i.e.* in the fibrous tissue surrounding it) I have ascertained that the smallest lymphatic vessels consist of nucleated fusiform or irregularly stellate cells[2]. In some of my preparations the position of the nucleus is indicated by an oval or roundish light space, the other parts of the cell being filled with injection (see Pl. VI. fig. 1). It may naturally be asked, Are then those fusiform or irregularly stellate cells which have been injected the connective tissue bodies such as have been described by Virchow and others? To this query I think I may safely reply in the affirmative, although it must be confessed that in many instances the processes so injected do not bear a very strong resemblance to these corpuscles when uninjected. But this circumstance I consider to be chiefly due to the cells being distended and thus altered in size and form. The expansion of these cells also into lymphatic radicles (which only become visible when thus injected) and the extreme obliquity with which they anastomose with one another and join the larger lymphatic trunks, tend altogether to render observations on single corpuscles in many instances a matter of extreme difficulty. In the fibrous tissue of certain parts however the fine processes which emerge from the capillaries bear a very strong resemblance when injected to fibrous tissue corpuscles. This is well seen in a preparation which I possess[1] of the membrana nicticans of the cat. I have also seen fusiform bodies similar to these in an injected tendon from the same animal and one from the neck of the domestic fowl.

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[1] [In a paper, which I read at the meeting of the British Association at Bath in September, 1864, I described (*Med. Times and Gazette*, Sep. 24, 1864), a peculiar relation between the superficial branches of the hepatic artery and the lymphatics. In the pig each branch of this artery is accompanied by two lymphatic trunks which run parallel and in contact with it, and are, as it were, braced together here and there by short transverse branches, which pass both above and below. In this way the artery is more or less ensheathed in lymphatics. In man this arrangement reaches a much higher degree of development, the hepatic artery being in fact enclosed in a fenestrated lymphatic tube. With each expansion of the artery the lymphatics are compressed and their contents propelled towards the heart. Note, 1869.]

[2] The drawings Pl. VI, figs. 3, 4 exhibit very well a phenomenon which I have observed in large numbers of my injections, and which I may be allowed to call attention to here. It is that the so-called nuclei of the capillaries are filled with injection, and stand prominently out from the sides of these vessels when thus distended. From this fact, which I consider very important, it follows that instead of their being oval bodies simply imbedded in the wall of the capillaries, they must (in some instances at least) be regarded as nucleated tubular swellings connecting the blood-vessels with the diaplasmatic system; for I have seen a fine process given off by these nuclei when uninjected which was in every respect similar to the prolongations of the connective corpuscles, and I have satisfied myself by injection that these corpuscles do communicate with the nuclei of the capillaries. Moreover, as it will be seen hereafter that I have succeeded in pushing the injection into one of the fusiform bodies found among the fibrillæ of muscle, and also into the lacunæ and canaliculi of bone, I cannot but consider that the whole of these corpuscles and their prolongations belong to the system which I have named diaplasmatic. It is possible also, I think, that the nuclei of nerve fibres belong to the same category; but of this I have not assured myself by observation.

In sections taken from a human thyroid body which I injected from the blood-vessels, the communications of the hæmal and lymph systems can be made out with tolerable facility. In the stroma of this gland the finest lymph-vessels appear to form an exceedingly minute network connected on the one hand with the blood-vessels and on the other merging into the larger lymphatic trunks with which the intervesicular tissue is largely supplied. The general character of the network may be seen in Pl. VI. fig. 7. Sections from the same organ also exhibit another hollow plexus having similar vascular relations. This network however is intra-vesicular and varies in fineness or coarseness according as the cell-elements of the particular vesicle vary in size (see Pl. VI. fig. 7). The network of the thyroid vesicles which I have succeeded in filling with injection correspond in all probability with the trabecular arrangement described by Heidenhain (Moleschott's *Untersuchung*. 1858) as existing in the interior of the glands of a Peyer's patch. I have indeed injected a similar network in the little glandular spots of the frog's intestine, which I think must be regarded as the Peyer's glands of this animal[2]. The capillaries which lie around these spots are enlarged to two or three times their usual diameter, and give off fine processes which unite to form a dense plexus in the meshes of which the cell-elements are placed. I have also noticed an arrangement similar to this in the outer vesicular portion of a lymphatic gland from the abdomen of the cat. In neither of these instances have I as yet been able to discover a lymphatic vessel arising from the networks.

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[1] [The Royal Society copy contained a figure of injected fibrous tissue corpuscles in this structure, but the illustration in Pl. VI, fig. 1, is sufficient for the present purpose. (Note, 1869).]

[2] [I have since injected the minute network in a Peyer's patch of the mouse, and through it the central lymph canal of a villus. (Note, 1869).]

I have now to mention a few more structures in which I have displayed these minute plexuses by means of injection; and although I have not been successful in tracing their connexion with distinctly recognisable lymphatics, I consider them in virtue of their position and minuteness to belong to this system of vessels.

The fin of the perch, which I formerly mentioned as shewing the diaplasmatic network in the interosseous mucous membrane, exhibits also in a very beautiful manner the injection of the lacunæ and canaliculi of the minute bones (see Pl. VI. fig. 4). In this organ the larger blood-vessels run a course parallel with the bones—an artery and a vein for the most part on either side. From these are given off on the one hand the capillaries which supply the web, and on the other large or small branches, which either form loops on the surface of the bones returning to the vessels of the same side from whence they sprung, or, as more frequently happens, anastomosing with those given off from vessels on the opposite side.

In various parts of the bones of the fin small processes filled with injection may be seen connecting the capillaries with the bone corpuscles; and it is quite evident that fluids run freely from one lacuna to another through the intervening canaliculi[1].

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[1] [The discovery of the direct communication of the capillaries with the white fibrous tissue corpuscles and other diaplasmatics explains very satisfactorily, I think, a number of pathological phenomena which formerly were inexplicable. How, for example, the increase in the number of blood-vessels takes place in cases of inflammation, and also how after the subsidence of the inflammation the blood-vessels again return to their normal number. We have only to suppose the walls of the diaplasmatics to lose, like the blood-vessels, their ordinary tonicity (and this is what I hold occurs in inflammation), and the blood-globules would at once enter them converting them into blood-vessels. On the recovery of the diaplasmatics from their paralysed state, they would again resume their ordinary functions as bearers of filtered blood or liq. sanguinis. That an actual increase in the number of blood-vessels takes place in inflammation, and not a mere appearance of increase from the enlargement of those already existing, I have convinced myself by injection. I will give but one example of the rapid appearance and disappearance of blood-vessels. We know from absolutely perfect injections, that no blood-vessels can be seen in the human cornea; they

Some of the latter appear to communicate with large irregular cavities situated near the margin of the bone which I think there is every reason to suppose are the lymphatics of the part (see Pl. VI. fig. 4 c). The injection in the irregular cavities is much lighter in colour than it is in the capillaries lying close at hand, and of a finely granular aspect. Such appearances I have also noticed in the lymph-vessels of the thyroid and those of the true skin of the human fœtus and I regard them as characteristic of these vessels when injected through the blood vascular system.

An injected preparation of the scapula of a mouse which I possess also exhibits the lacunæ and canaliculi filled or partially filled with injection from one of the capillary vessels of the periosteum, and this without any observable extravasation[1].

More than two years ago (1862) on examining a portion of injected muscular substance from the diaphragm of the calf, I was greatly surprised to observe that the colouring matter had found its way within the sarcolemma of several fibres, and had extended, from the point of entrance, up and down the fibre almost from end to end. The only way in which such a remarkable phænomenon could be explained, I then thought, was by supposing that rupture of juxtaposed blood-vessel and muscular fibres had taken place, and that the injection had passed

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terminate in loops at its margin: but in inflammation of this organ, blood-vessels may be traced over the cornea even with the naked eye, and when the inflammatory action has subsided the blood-vessels may, and often do, entirely disappear. What we call a pathological phenomenon at one period of existence, is in truth but a physiological phenomenon at another: for this enlargement and conversion of diaplasmatics into blood-vessels in inflammation is what occurs naturally in young and growing animals; and it may be seen to perfection in the tail of the newt-tadpole. Here may be observed in the hyaline tissue, cells with numerous off-shoots which anastomose with the branches of neighbouring cells and also with the capillaries close by. The opening-up of the branches communicating with the capillaries may be witnessed in all stages of development if carefully looked for. I may mention too that the nucleus or cell occupying the cavity of the stellate corpuscle bears the strongest resemblance to —is indistinguishable from—the colourless blood-cell. Indeed I regard such cells or nuclei as the parents not only of white blood-cells, but also of pus-corpuscles, and in an abnormal mode of development of cancer-cells also. This view, I am aware, has been put forward by Virchow, and advocated by many pathologists, but when taken in connexion with my discovery by injection of the continuity of the capillaries with the diaplasmatics (white fibrous tissue corpuscles, bone corpuscles and their modifications), and of the capacity of these vessels, under certain conditions, to enlarge and open up, it explains the mode in which cancer germs travel from one part of the system to another, as from the mamma to the axillary glands. Note, 1869.]

[1] [I have also preparations of the spongy bones of the cat's nose which exhibit the injection of the lacunæ and canaliculi. (Note, 1869.)]

from the one into the other. But a further examination of the specimen, and more mature reflection, convinced me that I was not warranted in thus solving the difficulty; for had rupture of both blood-vessel and sarcolemma occurred in close proximity, the injection would have passed more readily between the fibres than have stripped the sarcolemma from the included fibrillæ. Had but one muscular fibre been so affected, this explanation might perhaps have been considered valid, but as several presented the same peculiarity, it was rejected as altogether inadmissible. The conclusion ultimately arrived at was, that a natural communication exists between the interior of the blood-vessels and the interior of the muscular fibres.

The injecting fluid used in this particular instance was of similar composition to that mentioned in p. 101. I have since produced precisely the same results in the muscular fibres of the sheep's tongue with the carmine and gelatine injection. In neither of these instances could I distinctly trace the vessels through which the pigment gained entrance to the interior of the muscular fibres, and some time elapsed before I was able to demonstrate these minute channels by means of injection. At length, however, a frog yielded the coveted preparation; and I can now show satisfactorily the communications in a thin sheet of muscle, composed of but a single layer of fibres, taken from the abdominal wall of this animal, see Pl. VI. fig. 5. In the specimens which I possess exceedingly delicate processes may be perceived coming off from the capillaries, passing through the sarcolemma, and then arranging themselves parallel with the fibrillæ. How or where these channels terminate—whether in the blood-vessels or in the lymphatics—I have not yet ascertained; but I think I have made out that they are in connexion with the nuclei situated among the sarcous elements,—at least I have traced the injection up to one of these nuclei, and have there seen it abruptly terminate. In addition to these fine hollow processes which enter the sarcolemma, there are others which unite to form an irregular network between the different fasciculi. In the frog I have been unable to trace the connexion of this inter-fascicular plexus with lymphatic trunks, but in the muscular substance of the tongue of the sheep and of man I have observed these delicate vessels in communication with others of much greater size, and which, on account of their irregular form and being filled with injection of a very light pink colour, I think I am warranted in regarding as lymphatic.

Since making these observations my attention has been directed by Dr Turner of Edinburgh to the researches of C. O. Weber (Virchow's *Archiv,* 1859) and of Böttcher, who have described the connective tissue corpuscles lying immediately to the outside of the muscular fibres as anastomosing with each other, and also sending out processes which are continuous with the sarcolemma, or even extend into the muscular fibre, so as to be connected with the nuclei or cells of this structure. From the descriptions of these authors, and more especially from the figure given by Weber of the appearance of the fibrous tissue-corpuscles in suppurating muscle, it appears to me in the highest degree probable that the networks which these observers saw lying to the outside of the fibres, but communicating also with the interior, are identical with those which I have succeeded in filling with injection from the blood-vessels, and through which injection gained access to the interior of the muscular fibres in the cases which I have before mentioned.

While on this part of the subject I may record another very interesting circumstance which I have frequently had occasion to notice, and which would seem to show that the muscular walls of the small arteries are supplied with blood-plasma directly from their interior. In the numerous sections I have made of injected organs and tissues, it has of course sometimes happened that a small blood-vessel has been divided longitudinally, so as to expose the inner lining of the vessel, and a cross section of the circular muscular fibres. In such instances I have occasionally noticed that when the injection-cast was withdrawn the interior of the vessel was transversely striated with the injection, the striation being in bands of about the width of the fibre-cells. This appearance did not at first particularly attract my attention. I thought that it was due to the inner lining being thrown into folds by the longitudinal contraction of the vessel, and that the injection was thus caught and retained in the rugosities; having, however, subsequently observed that the cut edges of the vessel exhibited red spots of injection in the muscular coat and exterior to some of the circular fibres, I was led to believe either that the injection had penetrated the organic fibres themselves, or that it had penetrated some minute diaplasmatic vessels bearing a close resemblance to them in form and size. The latter supposition would appear to be the more probable of the two; though, from what I have previously mentioned regarding voluntary muscle, it is not by any means impossible that the same phenomenon may happen to involuntary muscle also.

The only portion of the nervous system which has hitherto afforded me an unequivocal example of the plasmatic plexus is the retina, but I have also seen what I am disposed to think are indications of it in the brain of a human fœtus of the 5th month, and in the ganglionic portion of the spinal cord of a cat. The retina which exhibited the network (see Pl. VI. fig. 3) was obtained from the last-named animal, and it is only in spots, here and there confined principally to the fundus, that it is capable of being distinguished. Concerning its relation to the cellular elements of the organ I am able to give no information, in consequence of the membrane having been dried on glass before I was aware of the existence of the network. Its minuteness and delicacy when injected are, however, so very great that it is questionable whether it could be seen at all in the natural semi-opaque condition of the organ.

I have now mentioned all the more important facts which have been elicited during my investigations, and which bear directly upon the distal communication of the blood-vascular with the lymphatic system, or which illustrate how widely distributed are the plasma-conveying channels in the vertebrate organism. My researches would seem indeed to justify the conclusion that such channels are common to all organs and tissues with the exception of articular cartilage, in which I confess I have not yet been able to detect anything approaching to a reticular arrangement[1].

[[1] Shortly after writing the above I made a number of special observations on the structure of cartilage, and I discovered in sections taken from one of the bones of the human wrist, and stained with carmine, clear evidence of reticulation. This reticulation I suppose to represent the channel system of cartilage, though I have no further proof of it to offer than that the reticulations pass from the margins of the cartilage lacunæ, and that I have here and there observed granules, apparently fatty, lying in the direction of the lines of the network, and as I believe in the plasma canals. See Pl. VI. fig. 6. I may here state that I

To some it may appear strange that previous investigators of the vascular system have never succeeded in distending these plexuses with the mineral colouring matters which are usually employed. This circumstance, however, will not appear at all surprising when we take into consideration the extreme minuteness of the diaplasmatic channels, and the difficulty ordinarily experienced in making a perfect, or even tolerably perfect, injection of the capillaries with such materials. Who, for example, has ever seen a brain or retina perfectly injected with vermilion or chromate of lead? Yet with the carmine fluid both of these organs may be injected with comparative ease and certainty. Looking, indeed, at the tendency shown by the finest mineral pigments to attach themselves to the parietes of the vessels, and finally choke them up, and furthermore considering the extreme minuteness of these diaplasmatics, I do not think it possible that they will ever be demonstrated, in the higher animals at least, by means of such injections.

With regard to the offices performed by these fine tubular networks, I have for the present but little to say, except that I consider all those found in the epidermal or mucous tissues to be especially and peculiarly connected with the function of secretion, and probably also but in a minor degree with that of absorption; while those situated in the deeper parts of the organism, such as muscle, fibrous tissue, &c. are employed in conveying blood-plasma to, and effete matters from, the tissues through which they run or with which they may be in contact[1].

PLATE V.

Fig. 1. Portion of mucous membrane of Frog's palate as seen with $\frac{1}{4}$-inch objective:—*aa′*. Capillaries. *bb*. Blood-corpuscles. *c*. granular nucleated pervious network. *c′*. Ditto injected. *d*. Deep and *d′*. superficial view of nucleated cells of mucous membrane.

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now entertain the opinion that every living cell or fibre of the higher organisms is in direct connexion at some part of its surface with a channel conveying nutritive fluid. (Note, 1869.)]

[1] I must here acknowledge my obligations to my friend Prof. Turner for many valuable suggestions which he has made, and also for his care in superintending the execution of the plates which illustrate this paper.

Fig. 2. Fold of mucous membrane of Frog's bladder:—*a*. Superficial layer of cells of mucous membrane. *b*. Granular nucleated pervious network. *c*. Deep layer of cells. *d*. Capillary.

Fig. 3. Injected lung of Toad ($\frac{1}{2}$-inch objective):—*a*. Capillaries. *b*. Plasma vessels (diaplasmatics) injected. *c*. Nuclei of cells of air vesicles.

Fig. 4. Lobule of Pig's liver (inch objective):—*a*. Outline of lobule. *b*. Large lymphatic trunks. *cc'*. Capillaries. *ddd*. Primary radicles of lymphatics.

PLATE VI.

Fig. 1. *a*. Lymphatic vessel of human liver lying above hepatic artery ($\frac{1}{6}$-inch objective). *b*. Fibrous tissue corpuscles filled with injection and connected with lymphatics.

Fig. 2. *a*. Lymphatic of Pig's liver, commencing in—*b*. Minute branching cell. *c*. Blood capillaries of capsule ($\frac{1}{6}$-inch objective).

Fig. 3. Retina of Cat (dried on glass and mounted in balsam) ($\frac{1}{4}$-inch objective):—*a*. Capillaries. *bbb*. Minute network (diaplasmatic). *cc*. Nuclei (?) of capillaries filled with injection.

Fig. 4. Pectoral fin of Perch 5 inches long ($\frac{1}{4}$-inch objective):—*aa*. Blood-vessels. *bb*. Capillaries. *c*. Minute network (diaplasmatic) in mucous membrane covering the bone. *d*. Bone corpuscles filled with injection from capillaries. *e*. Lymphatic vessel (?). *f*. Articulation of bones. *g*. Pigment cells.

Fig. 5. Muscular fibre of Frog ($\frac{1}{2}$-inch objective) showing capillaries and fine injected processes passing from them into the interior of the fibre.

Fig. 6. Cartilage from bone of human wrist stained with carmine, and showing delicate reticulations (plasma channels?) with granules here and there ($\frac{1}{4}$-inch objective).

Fig. 7. Section of portion of injected human thyroid ($\frac{1}{2}$-inch objective):—*a*. Artery. *b*. Capillaries. *cc*. Large lymphatic trunk surrounding artery. *d*. Plasmatic network in thyroid vesicle communicating with capillaries and lymphatic.

Fig. 1.

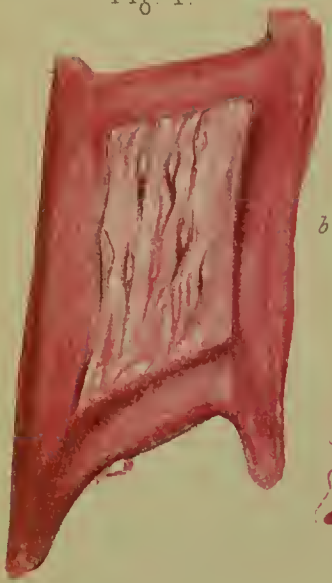


Fig. 2.

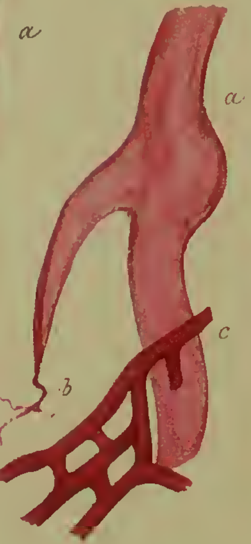
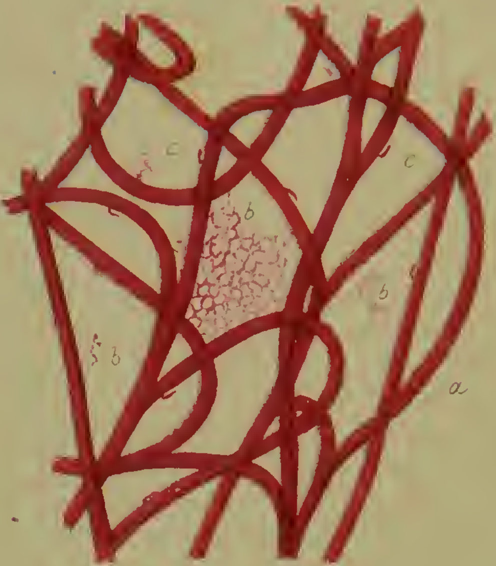


Fig. 3



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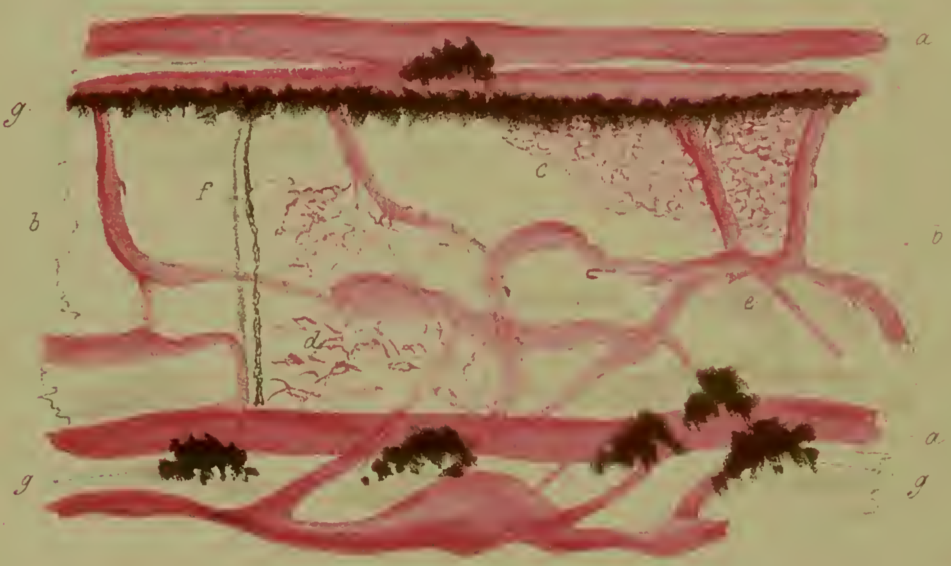

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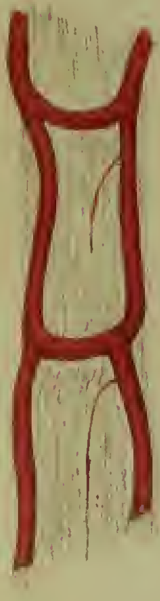

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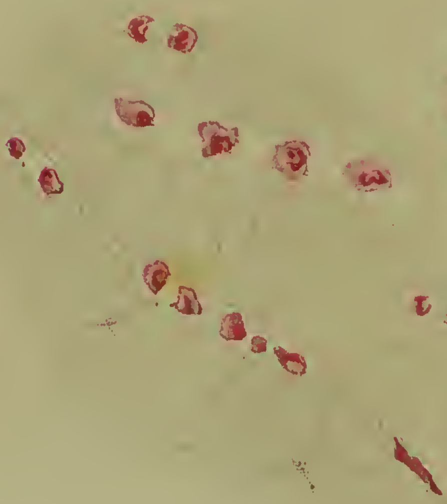

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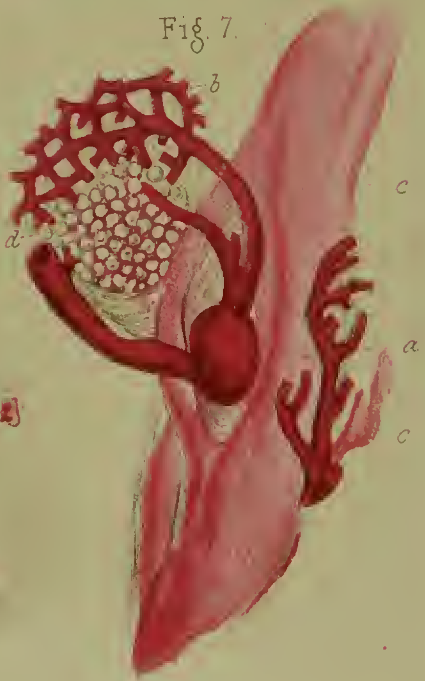


Diaplasmatic Vessels

T. A. Carter, del^t

W H M^c Farlane, Lith^r Edin^r

Fig 1

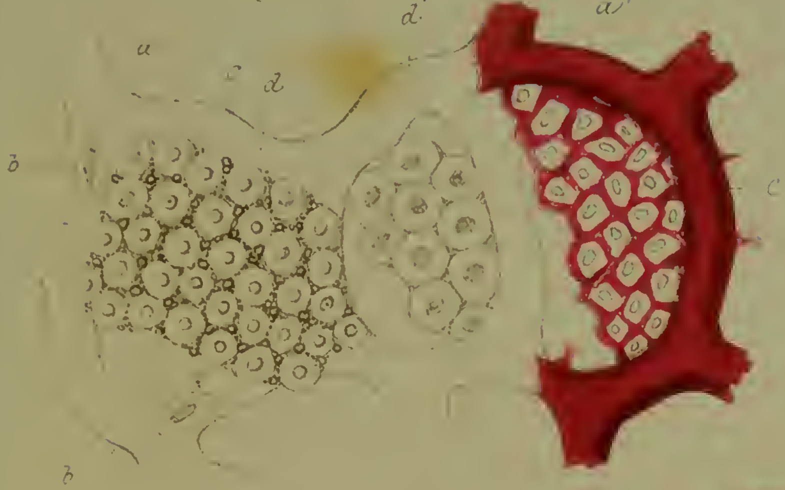


Fig 2

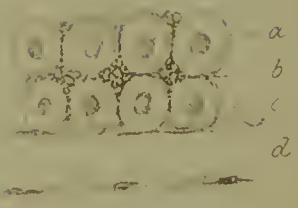


Fig 3

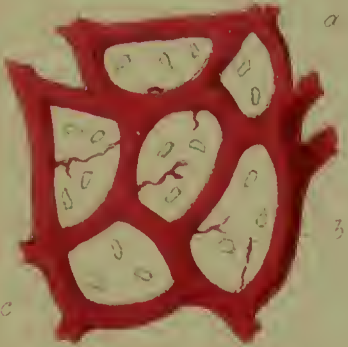
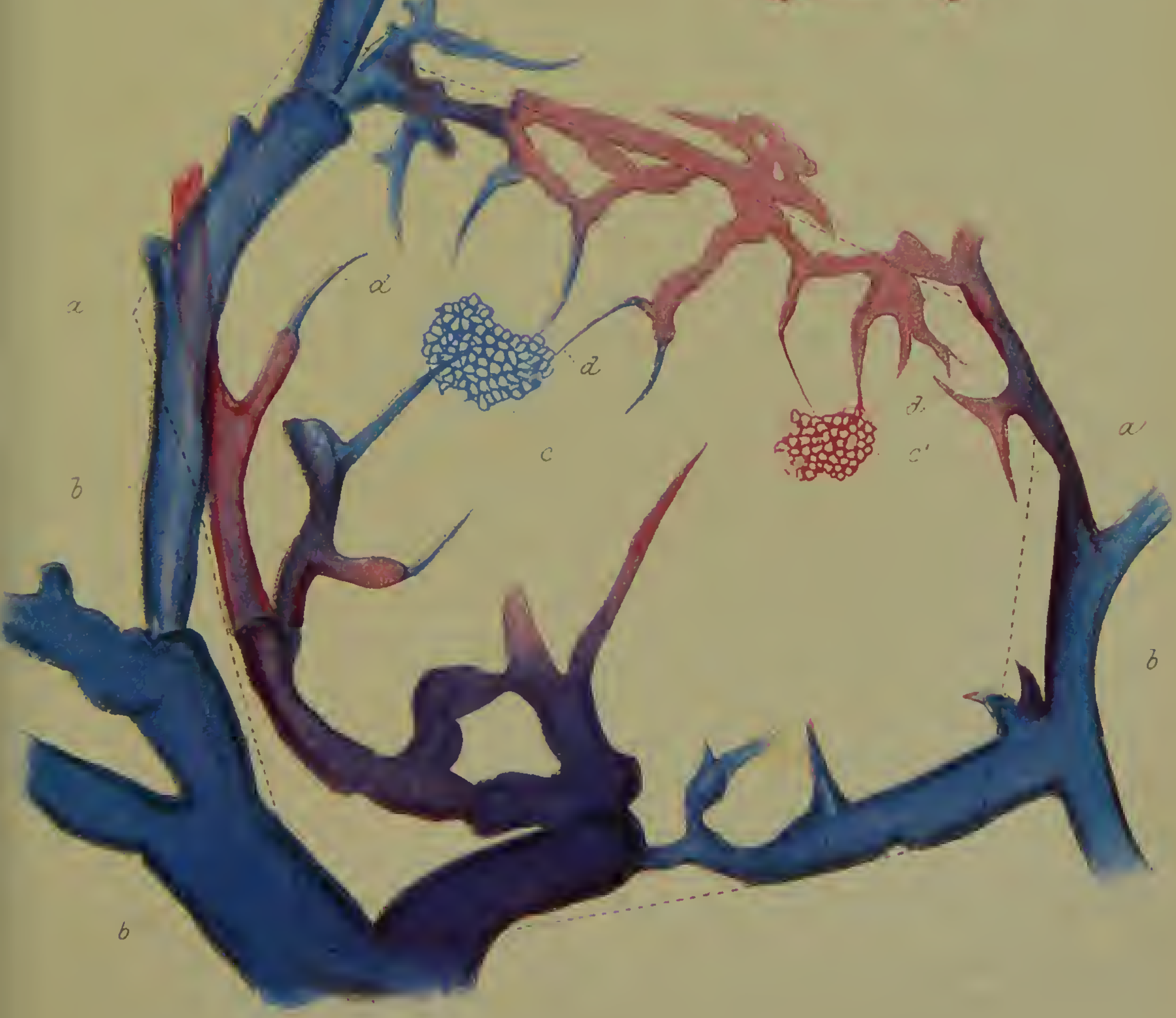


Fig 4



Diaplasmatic Vessels.

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